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Effects of liming and deciduous litter on earthworm (Lumbricidae) populations of a spruce forest, with an inoculation experiment on Allolobophora caliginosa

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I. Introduction

Earthworms are known to exert a beneficial influence on several properties of the soil. They improve aeration, water-retaining capacity, and nutrient status, enhance decomposition by mechanical breakdown and microbial stimulation, and are the chief agents responsible for the crumb structure and mull formation typical of fertile soils (for a review, see e. g. SATCHELL 1967; EDWARDS & LOFTY 1972).

Coniferous forest is not the best possible habitat for earthworms. The dry heath forests of Finland and Scandinavia usually harbour only *Dendrobaena octaedra*, although sometimes also *D. rubida*. In forests of moister types, a third species is found, *Lumbricus rubellus*, but in rather low abundance (KARPPINEN 1958; NURMINEN 1967; ABRAHAMSEN 1972; NORDSTRÖM & RUNDGREN 1974). Deep-living species, which play the main role in mixing the soil components, are absent altogether. The main reasons for this are the acidity of the raw humus and the low palatability of coniferous litter to earthworms (LINDQVIST 1941; BORNEBUSCH 1953; SATCHELL 1955; NORDSTRÖM & RUNDGREN 1974).

If coniferous forest soil could be rendered more favourable for earthworms, their activity might increase and populations of burrowing species might be established, which would eventually benefit the whole ecosystem, and increase the productivity of the stand (cf. LINDQVIST 1941). Measures that suggest themselves are decrease of acidity by liming, and production of more palatable litter by interspersion of deciduous trees among the main tree species. In some instances introduction of populations into previously worm-free soil has been tried with success (BARLEY & KLEINIG 1964; VAN RHEE 1969). Liming has been reported to increase worm populations in spruce forest soil (FRANZ 1959, KLEINSCHMIT 1962).

2. Material and methods

The experiment was established in a spruce stand of *Oxalis-Myrtillus* type situated ca. 25 km north of Helsinki. The site had already been subjected to a 4-year survey (Loc. 1 in HUHTA et al. 1967), so that the composition of the Lumbricid community was known (NURMINEN 1967). The dominant species was *Dendrobaena octaedra* (SAV.), *D. rubida* (SAV.) was found sporadically, and *Lumbricus rubellus* HOFFM. constituted 11.8% of the mature specimens. *Allolobophora caliginosa* (SAV.) was not recorded. The data from the control plots of the present investigation agree well with these figures, except that the proportion of *L. rubellus* (juveniles included) was lower.

A representative area was selected, inside which twelve 3×3 m squares were chosen, as homogeneous as possible and without trees, stumps, stones etc. This was done to minimize the sampling error. These plots were used randomly for different treatments, which were:

(1) Control with no treatment.

(2) Litter of deciduous trees was applied on 8 Nov. 1972. Litter of birch *(Betula verrucosa)* and of alder *(Alnus glutinosa)* were mixed in a ratio of 2 : 1, corresponding to the annual litter fall of a mixed stand of birch and alder. The litter was obtained soon after leaf fall by collecting all the fresh litter from measured areas in pure stands of birch and alder. The application was repeated in October 1974.

Table 1. Nutrient analysis from the test plots on 2 June 1978

	Duplicates	Conductivity	pH	Ca exchangeable $mg \cdot l^{-1}$	K exchangeable $mg \cdot l^{-1}$	P easily soluble $mg \cdot l^{-1}$	Mg exchangeable $mg \cdot l^{-1}$	N in nitrates $mg \cdot l^{-1}$
Humus:								
Control	a	1.3	4.0	525	105	9.7	60	2.0
	b	1.1	4.1	300	85	9.3	40	1.4
Litter +	a	1.3	4.3	525	150	7.5	63	2.6
inocul.	b	1.5	4.3	600	132	10.0	82	2.2
Lime +	a	3.9	6.1	15000	100	9.5	270	2.3
inocul.	b	2.0	6.2	3300	125	12.0	100	2.2
Lime, litter	a	3.0	6.3	8000	110	13.0	240	2.2
+ inocul.	b	2.1	6.5	4800	170	20.0	160	2.0
Lime +	a	3.8	6.2	10000	115	8.6	250	4.0
litter	b	2.0	6.1	5800	110	14.0	130	2.5
Mineral soil:								
Control	a	0.6	4.1	10	50	2.5	28	<1.0
	b	0.7	3.9	10	42	2.0	26	<1.0
Litter +	a	1.7	4.4	10	68	1.7	40	<1.0
inocul.	b	0.6	4.5	25	80	1.9	50	1.2
Lime +	a	0.6	4.2	300	38	3.6	37	<1.0
inocul.	b	0.6	5.7	1100	68	5.2	53	1.3
Lime, litter	a	0.5	4.5	225	55	2.2	36	<1.0
+ inocul.	b	0.7	5.7	900	80	3.7	62	1.2
Lime +	a	0.4	5.0	600	55	2.0	40	<1.0
litter	b	0.6	4.3	250	50	2.2	28	<1.0

Table 2. Numbers and biomasses of earthworms (mean ± standard error) in the test plots.

	Numbers · m^{-2}			
		Inoculated		
	Control	Litter	Lime	Lime + litter
Average May 1975—May 1977 (n = 20):				
D. octaedra	50	70	119	95
L. rubellus	6	54	70	98
A. caliginosa	0	2	18	9
Total	**56**	**126**	**207**	**202**
10. October 1977 (n = 10):				
D. octaedra	37 ± 15	83 ± 27	69 ± 13	86 ± 16
D. rubida	0	0	2	2
L. rubellus	2 ± 2	51 ± 18	46 ± 12	76 ± 16
A. caliginosa	2 ± 2	8 ± 6	16 ± 11	11 ± 5
Total	**40 ± 15**	**142 ± 48**	**132 ± 26**	**176 ± 18**
7 September 1978 (n = 10):				
D. octaedra	104 ± 24	120 ± 19	115 ± 15	88 ± 20
D. rubida	0	0	32 ± 14	21 ± 10
L. rubellus	2 ± 2	13 ± 7	24 ± 6	27 ± 8
A. caliginosa	0	11 ± 9	131 ± 58	46 ± 16
Total	**105 ± 24**	**144 ± 29**	**302 ± 56**	**182 ± 32**

n = number of sample units per treatment. For *A. caliginosa* the figures are representative only

(3) Liming. 1 kg lime[1]) per square metre (= 10000 kg/ha) was applied on 8 Nov. 1972.
(4) Litter + liming. Treatments 2 and 3 together.
100 adult specimens of *Allolobophora caliginosa* were inoculated into each of the test plots 2 to 4 (50 on 1 May and 50 on 14 May 1973).
(5) Litter + liming, but with no inoculation of worms.
(6) No treatments, but *A. caliginosa* introduced.
Each treatment was applied to two replicate plots.

Samples were taken every spring and autumn from 1975 to 1977. The first five samples were intended only for monitoring the state of the populations. They comprised two 25×25 cm quadrats of litter and humus, down to the mineral soil, taken randomly from each plot. Samples for statistical treatments were taken on 10 Oct. 1977 and 9 Sept. 1978, comprising 5 units from each plot (= 10 per treatment). The worms were extracted from the samples with the heat extractor described by HUHTA & KOSKENNIEMI (1975). The worms seen on the mineral soil at sampling were picked by hand. In addition, at the last sampling (Sept. 1978), worms remaining in the mineral soil were collected by sieving and hand-sorting of the topmost 10 cm of the mineral soil immediately after removal of the quadrat samples. The control samples of Sept. 1978 were not taken from the original control plots but from the immediate vicinity of each treated plot, to see whether any dispersion of the introduced populations of *A. caliginosa* had occurred.

Conductivity, *p*H and content of main nutrients were analysed on 15 May 1978. The measurements were made from pooled samples of five 125 cm³ units from each plot. The analyses were performed by Viljavuuspalvely Oy (Fertility Service Ltd.), Helsinki.

3. Results and discussion

3.1. Establishment of the population of *A. caliginosa*

Up to October 1977 no specimens of *A. caliginosa* had been captured from plots which received no treatments except the inoculation. However, one juvenile specimen was obtained from a control plot, and another from a plot treated with lime and litter but not inoculated. In Sept. 1978 no *A. caliginosa* were found outside the treated plots.

At the end of the survey the introduced populations still existed in all treated plots (litter, lime and both). In the plots which had received only litter, however, the density and biomass remained low and no worms were recovered from the mineral soil. In the lime-treated plots (with or without litter) the population of *A. caliginosa* was especially strong in Sept. 1978, when the species constituted 25—43% of numbers of all earthworms and more than half of the biomass. (Though the sampling before 1978 did not recover all specimens, the increase in the population by the time of the last sampling can be taken as certain.) There were also differences between replicates: in each treatment considerably more worms were obtained from one of the replicates. The worms had also penetrated the mineral soil, especially in those plots where the population was dense. The higher *p*H and content of calcium (Table 1) in one of the replicates of treatments (3) and (4) are a clear indication of their activity, and mixing of the humus horizon into the mineral soil had also started, though not yet to any great extent.

According to SATCHELL (1955), the occurrence of *A. caliginosa* is limited to *p*H $\geqq 4.7$, though NORDSTRÖM & RUNDGREN (1974) reported the occurrence of the species at *p*H 4.2, and sometimes, as a sparse population, even down to *p*H 3.6. The *p*H of the litter-treated plots was slightly higher (4.3 in the humus) than that of the control (whether as a result of the treatment or not; see Table 1). Maybe even this small difference is of importance to the species at the lower end of its *p*H range. The *p*H of the humus in the limed plots was high enough to permit full growth of populations. Without the activity of *A. caliginosa*, the influence of liming remained superficial (Table 1).

3.2. Influence of the treatments on the existing populations

During the first five years the average population densities of both *D. octaedra* and *L. rubellus* were higher in all treatments than in the control plots. In *D. octaedra*, the difference was roughly twofold (Table 2) but could not be proved statistically significant (Table 3).

1) Dolomite lime, CaO + MgO, content of Ca 35%, Mg 7%.

in *L. rubellus*, the increase was 10- to 20-fold and statistically significant. Lime alone and litter alone increased the populations to about the same extent, and both treatments together seemed to result in a further increase in *L. rubellus* but not in *D. octaedra*.

At the last sampling, ca. 6 years after the establishment, the population density of *D. octaedra* was roughly the same in all test plots, including the controls. A decreasing trend during the period of observation can also be seen on *L. rubellus* (Table 2). The differences between the lime treatments and the control were still highly significant in Sept. 1978 (Table 3), while the plots with litter only did not differ significantly from the untreated soil. Liming also caused a shift in favour of *D. rubida*, while litter alone had no effect on this species.

4. Conclusions

It was demonstrated by the experiment that existing populations of Lumbricidae in spruce forests can be increased, and that introduced populations of burrowing species can be established by these simple treatments. Mere application of easily palatable litter is enough to cause a distinct effect even without artificial manipulation of the *p*H. This is of importance if the treatments are to be applied on a practical scale: to reduce the acidity in large areas, considerable amounts of lime would be needed, while just a reduction in herbicide treatments is all that is required to produce more leaf litter. In the present experiment the effect of litter application as compared to that of liming was only temporary, but the annual production of litter by living trees may be expected to cause a permanent change in the soil conditions. Many species of earthworms, including *L. rubellus*, feed very eagerly on alder. Birch leaves are also commonly eaten, while coniferous litter is seldom attacked (Lindqvist 1941, Bornebusch 1953). *A. caliginosa* is not actually a litter feeder (Lindqvist 1941, Barley 1959), but litter of good quality may benefit this species at later stages of its decomposition. A dense population of Lumbricids can consume even more litter than a temperate deciduous forest can produce, and food is probably one of the primary determinants of earthworm populations (Satchell 1967). Litter standing crop is one of factors governing the local distribution of earthworms, as shown by Phillipson et al. (1976).

	Biomass g d. w. · m^{-2}				
		Inoculated			
Lime + litter	Control	Litter	Lime	Lime + litter	Lime + litter
149	1.0	0.7	1.2	1.3	1.6
80	0.9	2.2	2.8	4.5	3.0
1	0.0	0.3	2.1	0.1	0.0
230	**1.9**	**3.2**	**5.1**	**5.9**	**4.6**
144 ± 33	0.3 ± .1	1.3 ± .5	0.8 ± .2	0.8 ± .2	1.9 ± .5
5	0.0	0.0	0.0	0.0	0.1
83 ± 22	0.0	2.1 ± .9	2.1 ± .7	3.3 ± .7	3.2 ± .6
0	0.0	1.6 ± 1.6	0.7 ± .4	0.4 ± .2	0.0
230 ± 35	**0.3 ± .1**	**5.0 ± 2.9**	**3.6 ± .9**	**4.7 ± .7**	**5.1 ± .9**
—	0.6 ± .1	0.7 ± .1	0.5 ± .1	0.5 ± .2	—
—	0.0	0.0	0.1 ± .1	0.2 ± .1	—
—	0.0	0.5 ± .3	1.4 ± .4	1.7 ± .7	—
—	0.0	0.2 ± .2	6.7 ± 2.4	2.7 ± .9	—
—	**0.7 ± .1**	**1.4 ± .5**	**8.7 ± 2.4**	**5.0 ± 1.2**	—

in September 1978.

Table 3. F values from the analyses of variance testing the effects of the litter and lime treatments on earthworms

	Litter	Lime	Interaction
10 Oct. 1977			
Numbers			
D. octaedra	2.95	<1	<1
L. rubellus	8.75**	6.78*	<1
Biomass			
D. octaedra	3.44	<1	2.50
L. rubellus	5.47*	5.55*	<1
A. caliginosa	<1	<1	1.17
Total	**3.27**	**<1**	**1.32**
7 Sept. 1978			
Numbers			
D. octaedra	2.02	2.23	<1
D. rubida	<1	8129**	<1
L. rubellus	1.48	9.37**	<1
A. caliginosa	<1	6.44*	3.46
Biomass			
D. octaedra	<1	<1	<1
D. rubida	<1	7.20*	<1
L. rubellus	<1	8.11**	<1
A. caliginosa	2.19	12.92**	2.61
Total	**1.16**	**18.40*** **	**2.63**

The asterisks denote the significance levels of $P < 0.05$, 0.01 and 0.001 (degrees of freedom 1,36)

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6. Summary · Zusammenfassung

Deciduous litter (birch + alder), lime, or both, were applied to test plots established in an *Oxalis Myrtillus*-type spruce stand in southern Finland. Living specimens of *Allolobophora caliginosa* were also introduced into the plots. The earthworm populations were examined for 6 years after the treatments.

The populations of *A. caliginosa* still existed at the end of the survey and were especially strong in the lime-treated plots. The populations did not become established in untreated plots, nor did they spread from the treated plots into the surroundings.

The treatments also led to increases in existing populations. *Lumbricus rubellus* was at first affected equally by lime and by litter, but towards the end of the survey the effect of litter alone diminished. The increase in *Dendrobaena octaedra* was more temporary and not statistically significant. The population of *D. rubida* increased significantly with liming.

Wirkungen der Kalkung sowie von Fallaubgaben auf Regenwurmpopulationen eines Fichtenwaldes, mit einem Besiedlungsexperiment mit *Allolobophora caliginosa*

In einem südfinnischen *Oxalis-Myrtillus*-Fichtenbestand wurden Versuchsflächen angelegt, auf denen entweder Fallaub (Birke + Erle), Kalk oder beides, samt lebenden Individuen von *Allolobophora caliginosa* zugeführt wurden. Die Regenwurmpopulationen wurden während 6 Jahren beobachtet.

Die Populationen von *A. caliginosa* existierten noch am Ende der Untersuchungsperiode und waren besonders stark auf den Flächen mit Kalkdüngung. Die auf den Kontrollparzellen ausgesetzten Populationen gingen zugrunde und die verbleibenden Populationen verbreiteten sich nicht außerhalb der behandelten Parzellen.

Die Behandlungen führten auch zum Zuwachs der ursprünglichen Populationen. *Lumbricus rubellus* wurde zuerst ebenso durch Fallaub und Kalk beeinflußt, aber gegen Ende der Periode verminderte sich lediglich der Einfluß des Fallaubs. *Dendrobaena octaedra* wurde durch die Experimente

nur zeitweise und statistisch insignifikant beeinflußt. Die Populationsdichte von *D. rubida* wurde durch Kalkung beträchtlich erhöht.

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